National Aeronautics and Space Administration

Investigation of Coupled Land-Atmosphere Carbon Dynamics and Seasonal Carbon Forecast Skill

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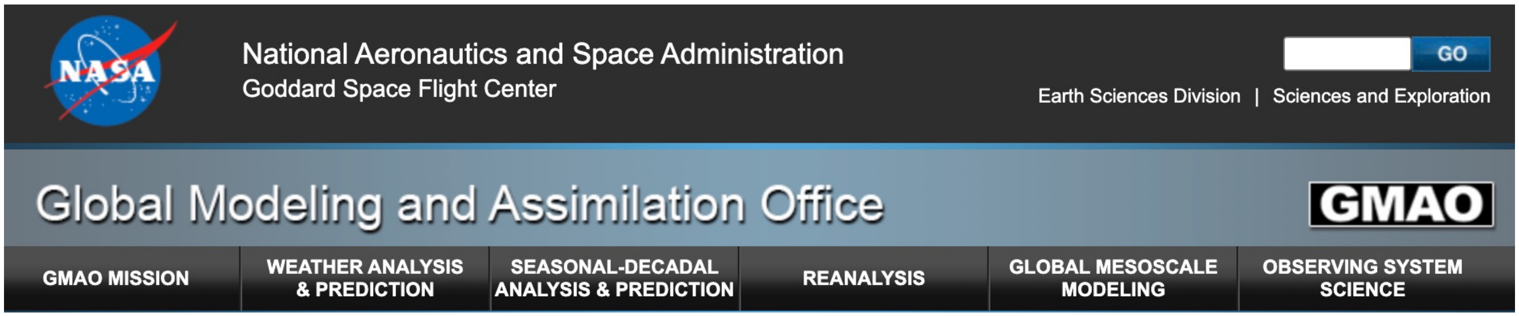
Overview

1. **Introduction**
   - Carbon in the atmosphere, and its sources and sinks
   - Evaluation of terrestrial carbon fluxes
2. **PART 1: Coupled land-atmosphere carbon dynamics**
   - Impacts of a regional Spring drought on land and atmospheric carbon
   - Effects of biomass burning aerosols and clouds on tropical land productivity
3. **PART 2: Predictability of the terrestrial carbon cycle**
   - Skillful seasonal forecast skill of land carbon uptake
4. **PART 3: Other ongoing research activities**
   - Improved hydrometeorological prediction with carbon cycle processes
   - Fire carbon dynamics
   - Application of S2S forecasts to water resources management
5. **Summary**

NASA Goddard Space Flight Center

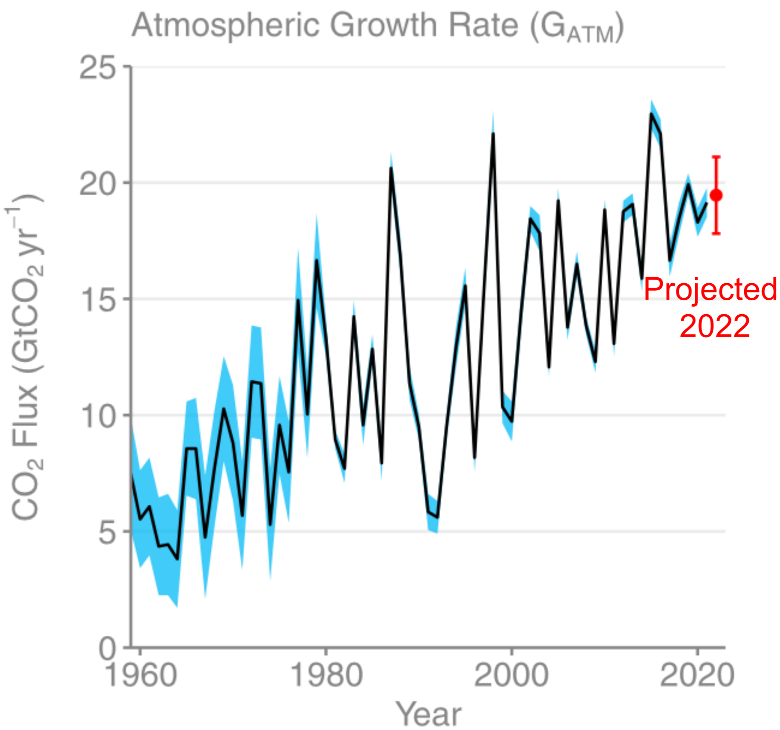
- Located outside Washington D.C. (Greenbelt, Maryland)
- Divisions: Earth Sciences, Astrophysics, Heliophysics, and Solar System
- Under the Earth Sciences Division (ESD)
  - Global Modeling and Assimilation Office
  - Goddard Institute for Space Studies
  - Laboratories that study the atmosphere, the hydrosphere, the biosphere, and geophysics

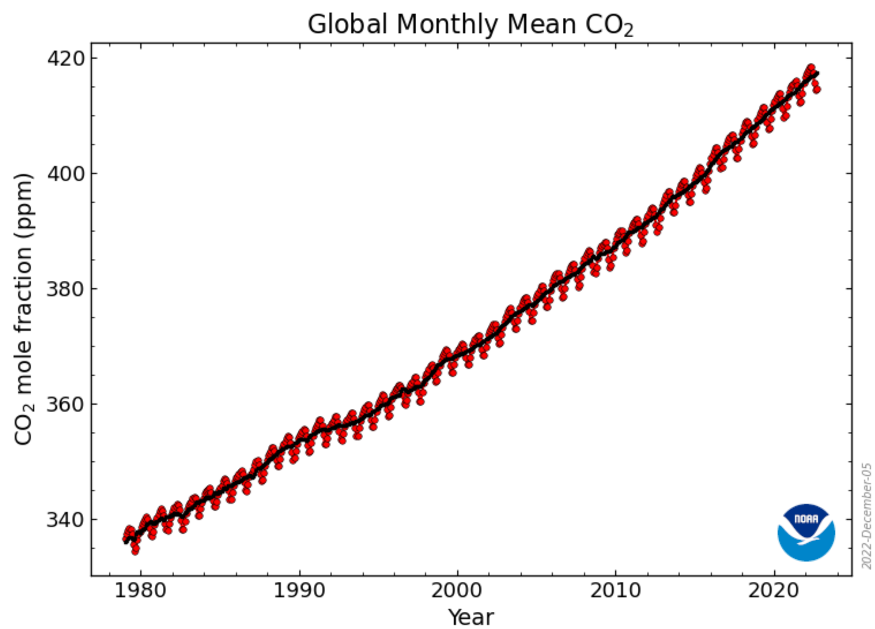
Global Modeling and Assimilation Office (GMAO)



- NASA GMAO's research activities
  - Development of NASA's Earth System Model
    - Global Earth Observing System (GEOS) model
  - Weather analysis and prediction, Seasonal-decadal analysis and prediction, Reanalysis, Global mesoscale modeling, Observing system science
- Major products
  - MERRA-2 reanalysis meteorology (1980-present)
  - GEOS subseasonal-to-seasonal (S2S) hindcast and forecast meteorology

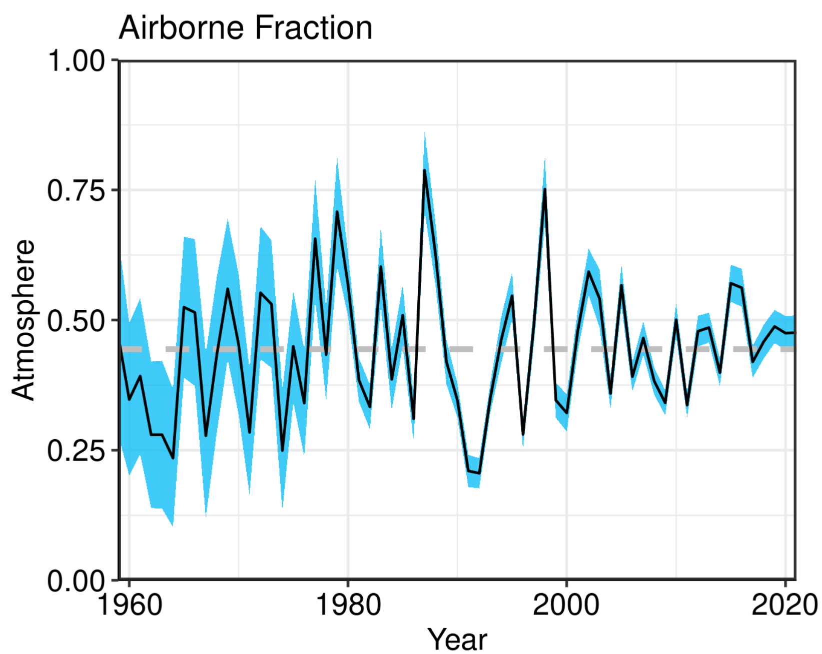
Carbon in the atmosphere





The growth rate of the atmospheric CO_2 concentration has gradually increased.

Airborne fraction of CO_2

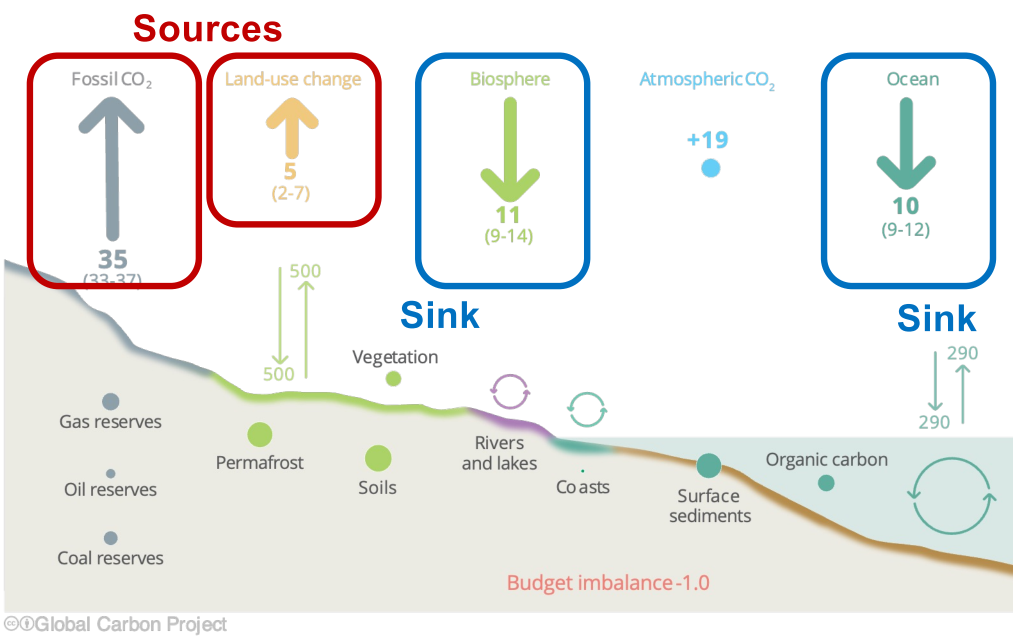


Airborne fraction

- The proportion of the total annual CO_2 emissions that remains in the atmosphere.

- About a half of CO_2 emissions (~45%) remain in the atmosphere. The rest of the emitted CO_2 are removed by the land and ocean sinks.

Dynamically changing global carbon cycle: Sources and Sinks



[Sources]

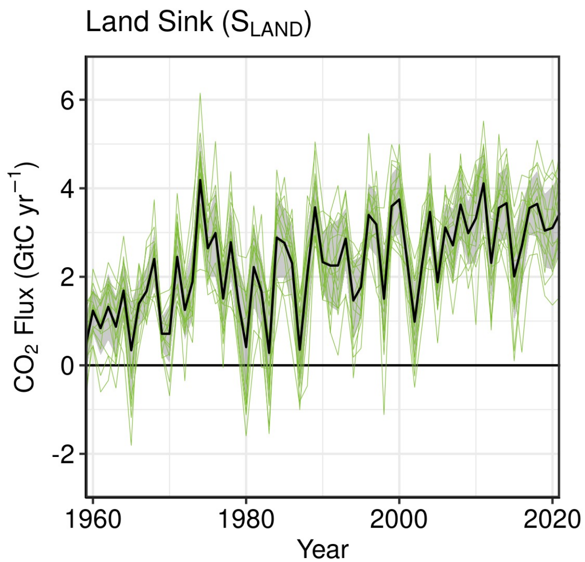
- Fossil emissions dominate in the Northern Hemisphere.
- Land-use emissions are important in the tropics.

[Sinks]

- The North Atlantic and Southern Ocean are ocean carbon sinks.
- Tropical, temperate, and boreal forests are the main terrestrial carbon sinks.

Friedlingstein et al 2022; Canadell et al 2021 (IPCC AR6 WG1 Chapter 5; Global Carbon Project 2022

Why is the terrestrial carbon cycle important?

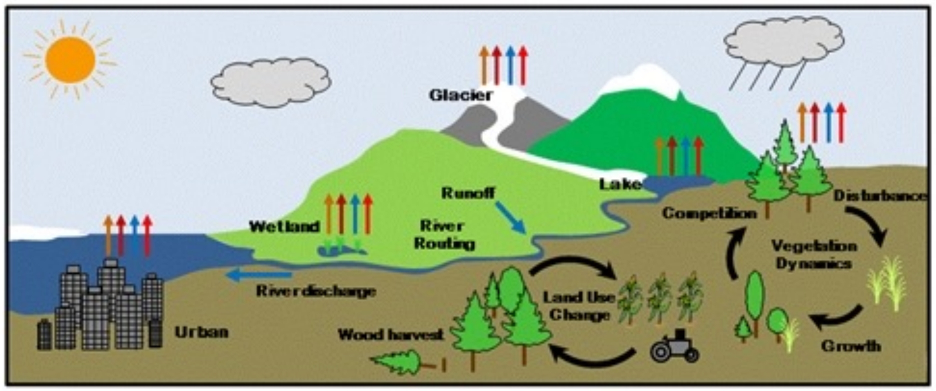


- High variability of the terrestrial carbon sink
- Estimated sink capacity of the land biosphere
  - 3.1 ± 0.6 GtC/yr (=11.4 ± 2.3 $GtCO_2$/yr) for 2012–2021
  - 3.4 ± 0.9 GtC/yr (=12.6 ± 3.3 $GtCO_2$/yr) in 2021
- If land's carbon uptake capability reduces in the future, it may accelerate warming and climate change.

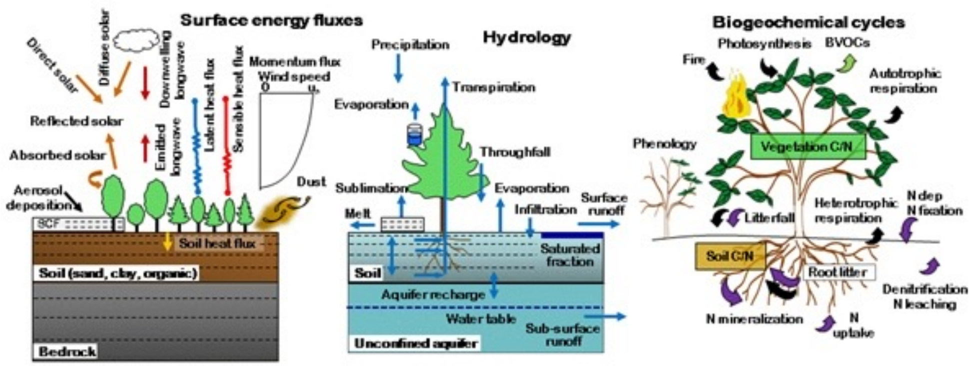
Earth system model (ESM) is defined as:
"A coupled *atmosphere–ocean general circulation model (AOGCM)* in which a representation of the *carbon cycle* is included, allowing for interactive calculation of atmospheric *carbon dioxide (CO_2)* or *compatible emissions*." (IPCC AR6 WG1 Glossary, 2021)

Friedlingstein et al 2022; Global Carbon Project 2022; IPCC AR6 WG1 Glossary

Land Surface Model (LSM) or Terrestrial Biosphere Model (TBM)
Simulating the natural processes of the terrestrial ecosystem

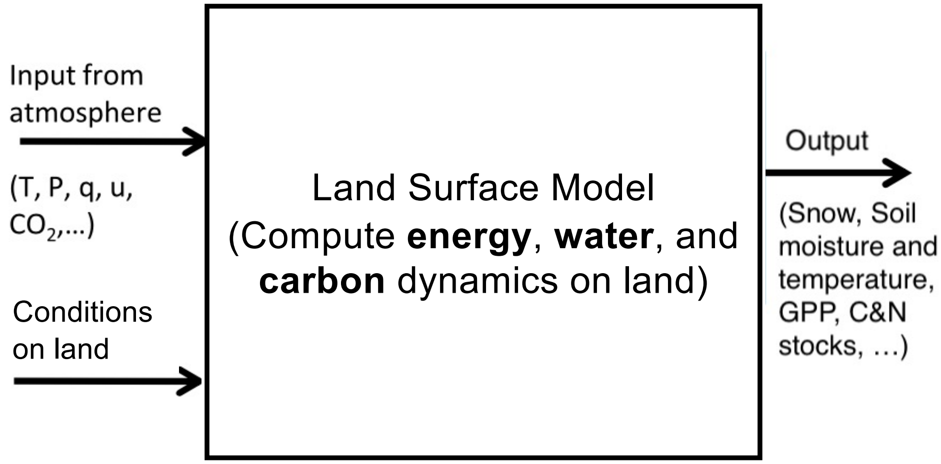


Energy cycle Water cycle Carbon cycle



https://www.cesm.ucar.edu/models/clm

Land Surface Model (LSM)



- Inputs to the land model
  - Meteorological variables (e.g., air temperature, rainfall, incoming radiation)
  - Initial condition of land (e.g., vegetation and soil status, land-use scenario)
- Outputs from the land model
  - Water variables (e.g., soil moisture, runoff) and carbon variables (e.g., GPP, NEP)
- Use as the stand-alone version (offline) or the coupled version to the atmosphere, serving as a land component in a GCM or ESM

NASA's Catchment-CN land model

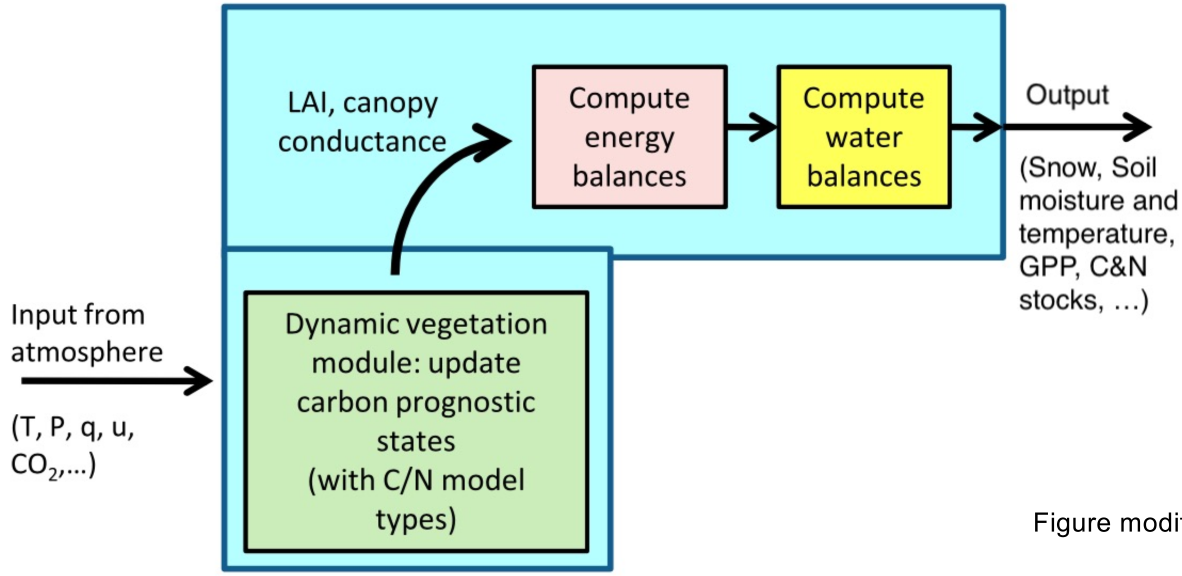
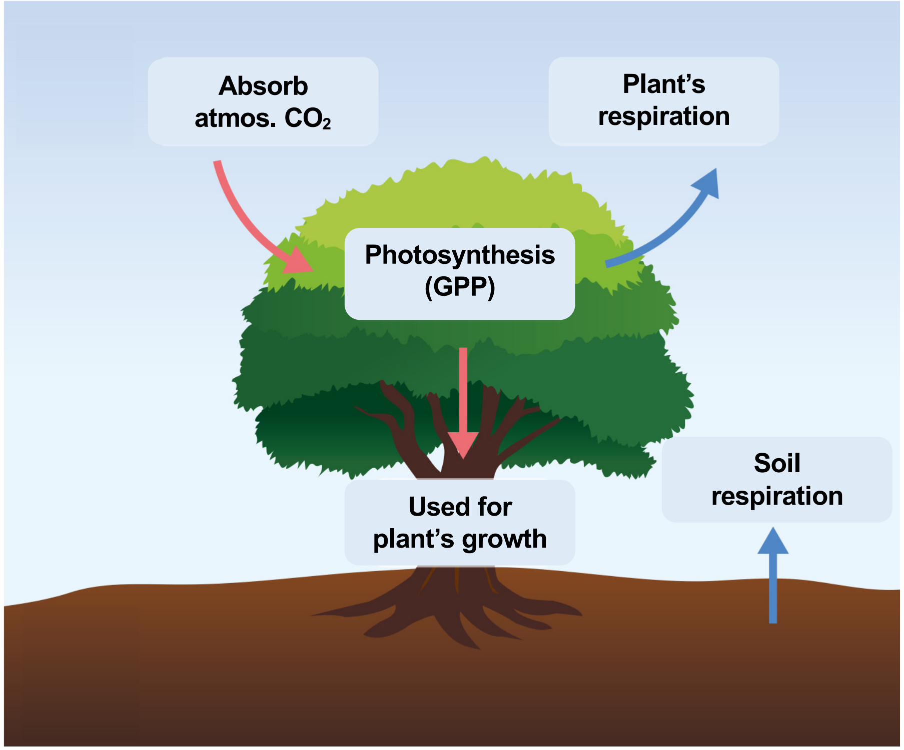


Figure modified from Koster et al. (2014)

- Use **energy and water dynamics** from Catchment LSM (Koster et al., 2000) developed in GMAO.
  - Explicitly treats the spatial variation within each hydrological catchment of the soil water, evaporation, runoff, and the water table depth.
- Merged **carbon and nitrogen dynamics** from NCAR-CLM (v4 and now integrating v5.1).
- Calculates energy and water dynamics at every 7.5 minutes and CN dynamics at every 90 minutes.
- Used as a land component in NASA GEOS model or offline (stand-alone version).

Terrestrial carbon cycle



Net carbon uptake by land ecosystem = GPP – Respirations – Fire – Land Use

How Catchment-CN computes land carbon dynamics

Leaf photosynthesis

- Farquhar model (Farquhar et al. 1980, Collatz et al. 1991 and Collatz et al.1992)*
- The minimum value of Rubisco-limited photosynthesis (ω_c), light-limited photosynthesis (ω_j) and export-limited photosynthesis (ω_e).

$$A = \min(\omega_c, \omega_j, \omega_e),$$

$$\omega_c = \begin{cases} \dfrac{V_{\mathrm{cmax}}(c_{\mathrm{i}} - \Gamma_*)}{c_{\mathrm{i}} + K_{\mathrm{c}}(1 + \frac{o_{\mathrm{i}}}{K_{\mathrm{o}}})} & \text{for C}_3 \text{ plants} \\ V_{\mathrm{cmax}} & \text{for C}_4 \text{ plants} \end{cases}$$

$$\omega_j = \begin{cases} \dfrac{(c_i - \Gamma_*)4.6\phi\alpha}{C_i + 2\Gamma_*} & \text{for C}_3 \text{ plants} \\ 4.6\phi\alpha & \text{for C}_4 \text{ plants} \end{cases}$$

$$\omega_e = \begin{cases} 0.5V_{\mathrm{cmax}} & \text{for C}_3 \text{ plants} \\ 4000V_{\mathrm{cmax}}\dfrac{c_{\mathrm{i}}}{P_{\mathrm{atm}}} & \text{for C}_4 \text{ plants} \end{cases}$$

V_{cmax} = maximum rate of carboxylation
c_i = internal leaf CO_2 partial pressure
ϕ = absorbed photosynthetically active radiation

Respirations

- Autotrophic respiration (R_a) and heterotrophic (soil) respirations (R_h) are based on the Q_{10} function of temperature and moisture.

Net Biosphere Production (NBP)

- **NBP > 0** : **Land** is a carbon **sink**
  (**Atmosphere** is a carbon **source**)
- **NBP < 0** : **Land** is a carbon **source**
  (**Atmosphere** is a carbon **sink**)

$$NBP = GPP - R_a - R_h - F - LU$$

*also as in CLM4 (Oleson et al., 2010)

Spinning up the land to build up the carbon reservoirs

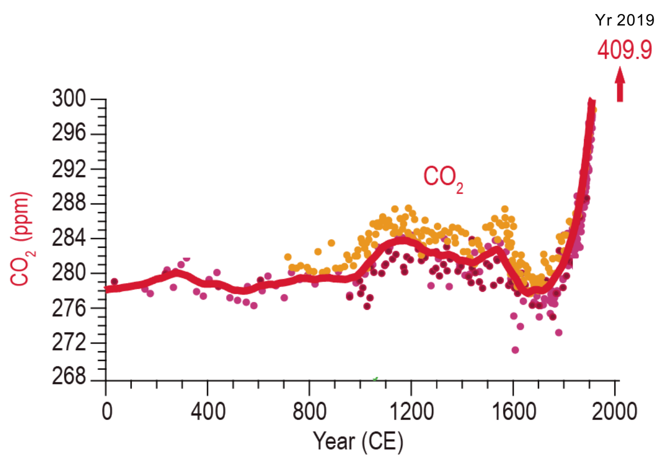
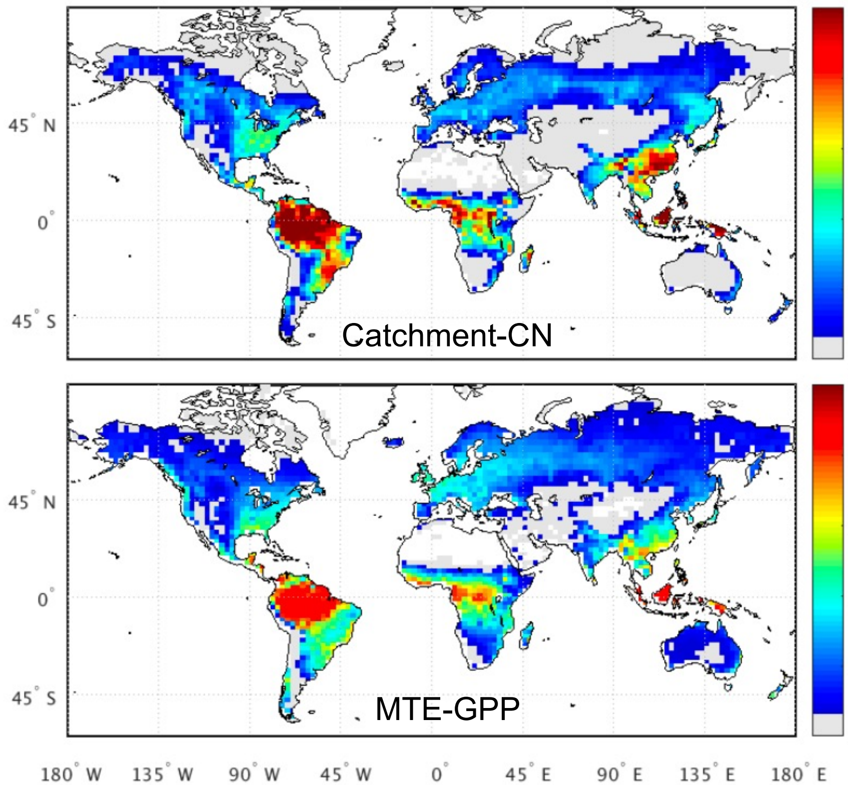


Figure 2.4 in IPCC WG1 Ch2 (2021)

- To mimic realistic land states (carbon, water and energy), **we first spun-up the model** to mimic the condition of the pre-industrial period, applying multiple cycles of 1981–2015 MERRA-2 forcing (at least 2,000 simulation years) **with 280 ppm of CO_2**.
- **We then drove the model** with additional cycles of the MERRA-2 forcing to represent **1850 to present with the steadily increasing CO_2 concentration** along the way to the present value (to mimic the transient character and carbon sink in Nature).
- The simulation produced the realistic carbon, water, and energy states (Lee et al., 2018).

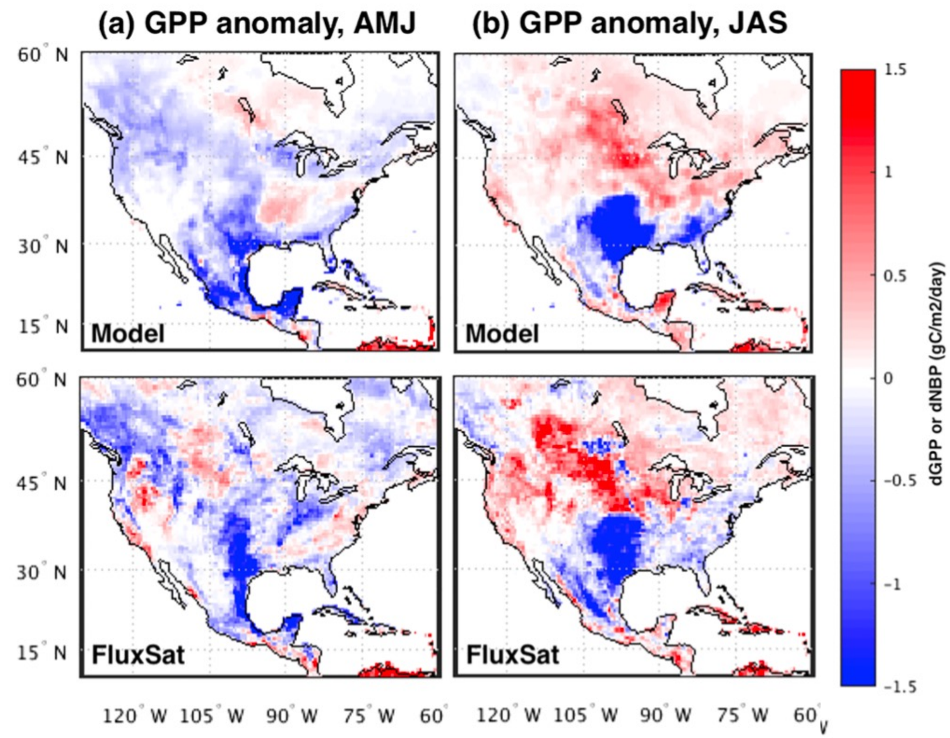
Validation of total carbon uptake

2002-2011 mean



Lee et al. (2018) *Biogeosci.*

Anomaly for 2011 TexMex drought

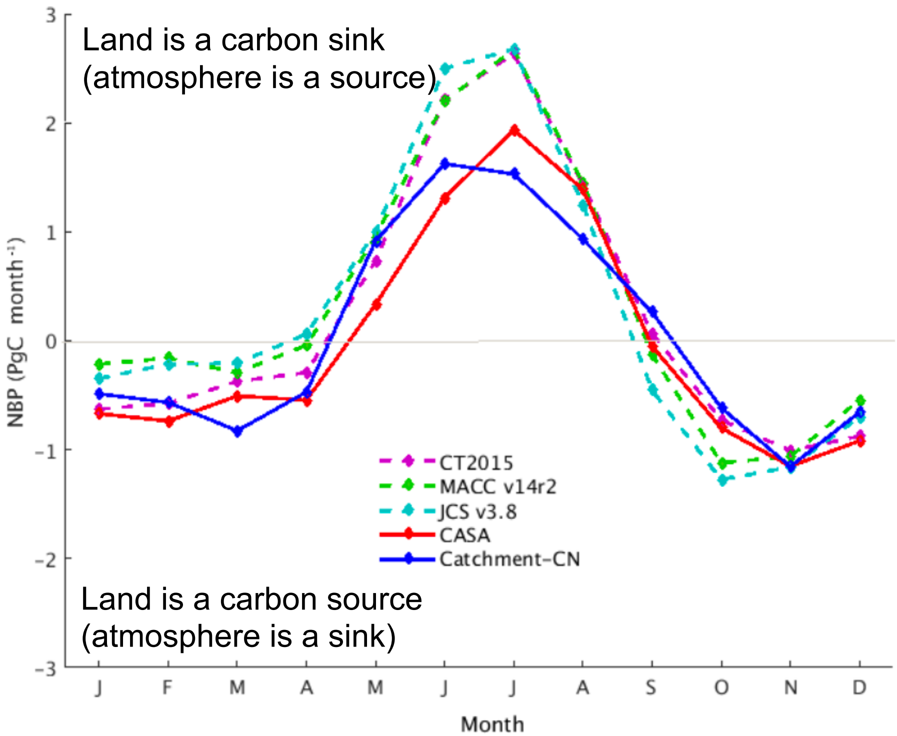


relative to 2003-2016 climatology

Lee et al. (2020) *JGR-bio*

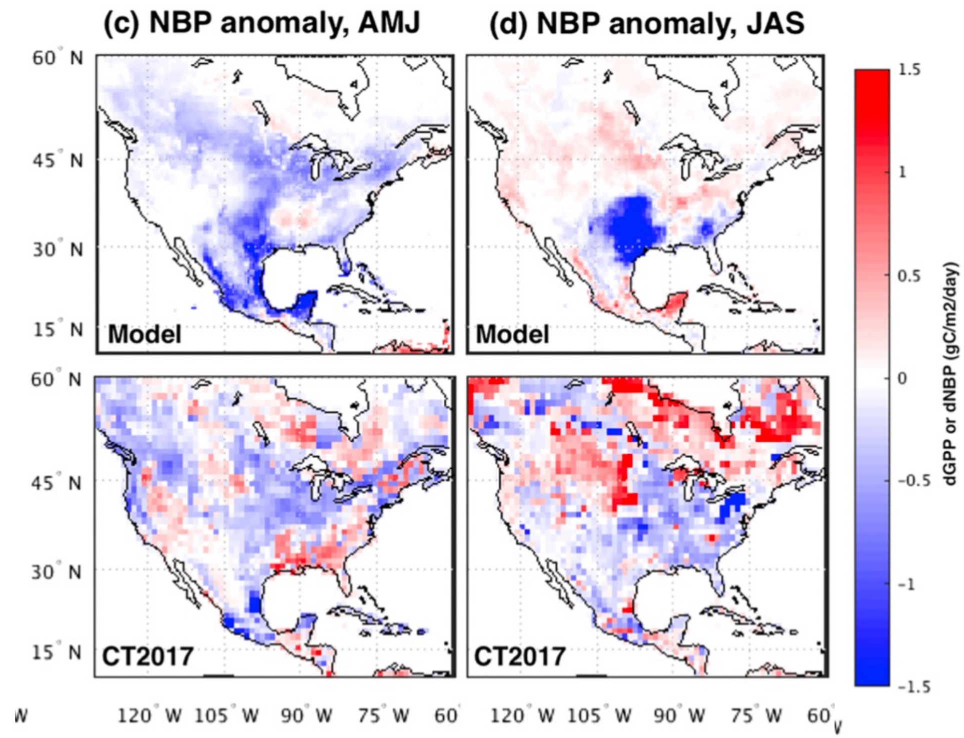
Validation of net carbon exchange

2004-2014 mean



Lee et al. (2018) *Biogeosci.*

Anomaly for 2011 TexMex drought



relative to 2003-2016 climatology

Lee et al. (2020) *JGR-bio*

PART 1: Coupled Land-Atmosphere Carbon Dynamics

(1) Impacts of a regional Spring drought to land and the atmospheric carbon

(2) Effects of biomass burning aerosols and clouds on PAR distribution and land productivity in the Amazon

Coupled L-A configuration of NASA GEOS model

NASA GEOS Earth System model

- Maintained by NASA GMAO.
- Widely used to study the interactions among the Earth system components. (e.g., Koster et al. 2016; Molod et al. 2012; Schubert et al. 2014; Wang et al. 2014)

Coupled L-A configuration of the GEOS model

- Allows coupled treatment of water, energy, and carbon dynamics in both the land and the atmosphere to feedback on each other.
- AGCM configuration (i.e., no coupled ocean component) to focus on the interactions between the atmosphere and the land ecosystem.

In the fully-interactive carbon version of the coupled L-A configuration,

- NBP flux from Catchment-CN is used as land carbon input at the surface layer in AGCM.
- Atmospheric CO_2 from AGCM is used to force the land ecosystem in Catchment-CN.
- NBP to near the surface is updated every 3 hours, and the transport of the atmospheric CO_2 is computed every 15 mins.

Impact of a regional Spring drought on land and atmospheric carbon

Background

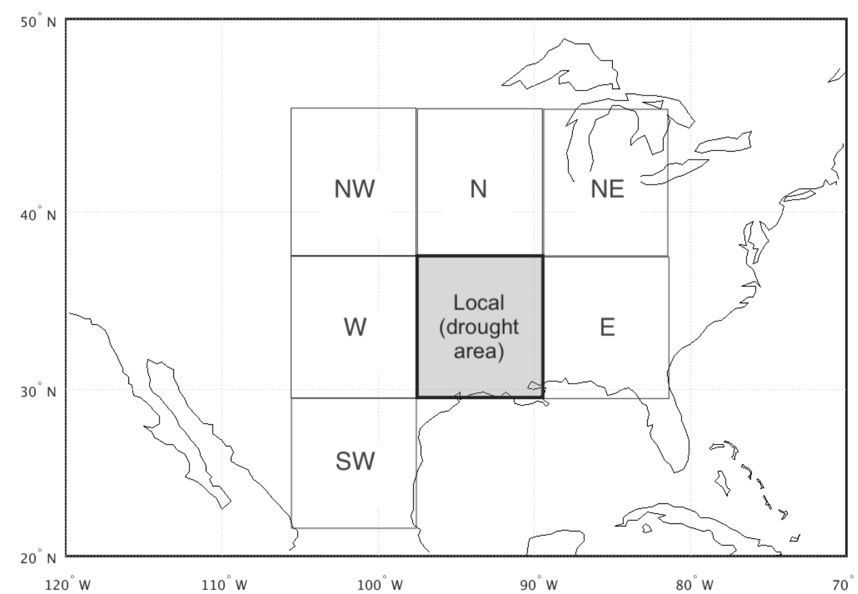
- Regional droughts can affect the amount of carbon absorbed by the land biosphere and the amount of CO_2 remaining in the atmosphere.
- Dry land conditions can also feed back on local and remote weather, which may further modify the carbon anomalies.

Research objectives

- To quantify the impact of a regional US drought on land and atmospheric carbon
- To gain a mechanistic understanding of the connection between a regional drought and carbon

Experimental design

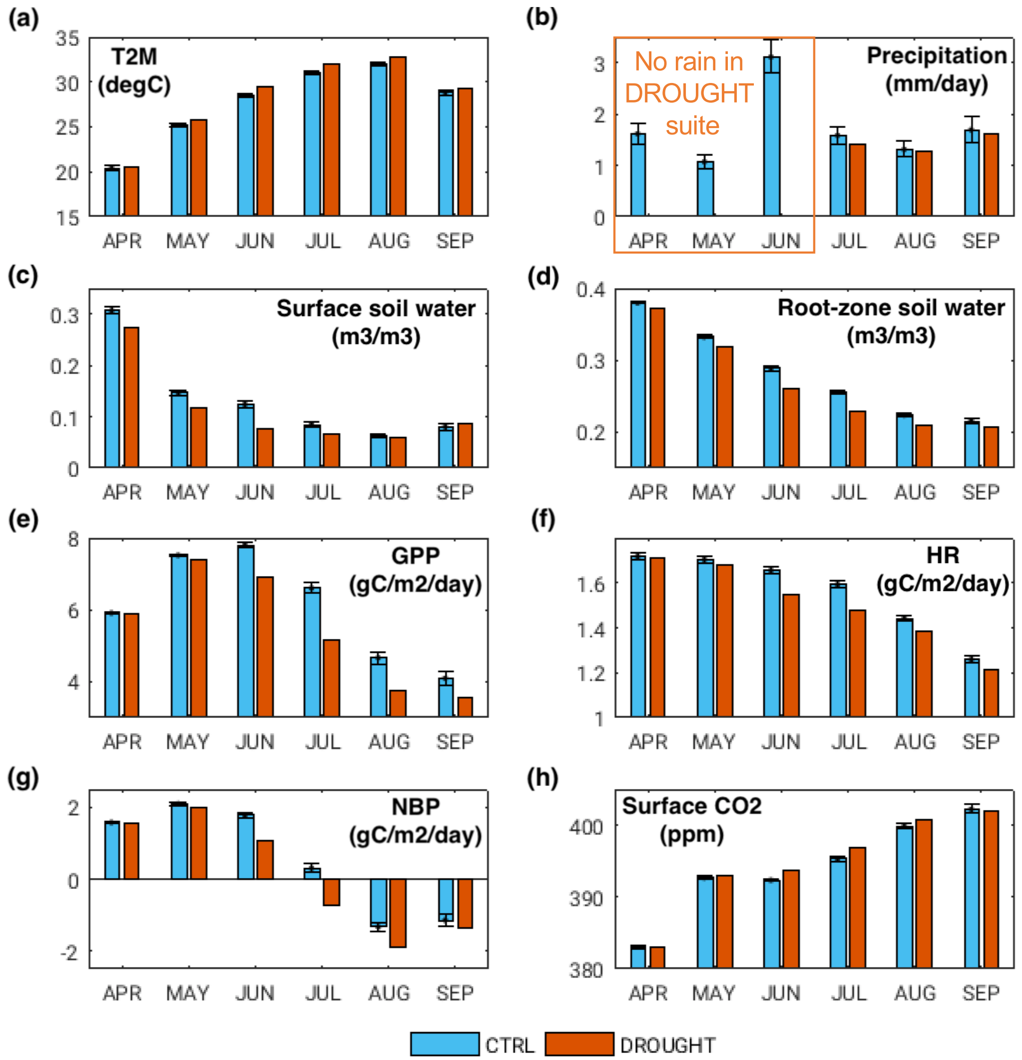
- Used a version of GEOS that **couples** the carbon, water, and energy cycles **across the land and the atmosphere**.
- Imposed an idealized spring drought for 3 months (AMJ) over the lower Mississippi River Valley (~500,000 km^2), followed by a 3-month recovery period (JAS).
- Applied the observed SST of year 2012 to all simulations
- C90 cubed-sphere grid (~1° x 1°)
- Each suite (CTRL and DROUGHT) consists of 45 simulations (free-run simulations).



Monthly average of air temperature, soil moisture, and carbon (CTRL vs. DROUGHT)

- In DROUGHT suite,
  - Higher air temperature
  - Depleted soil moisture
  - Reduction in GPP
  - Less net carbon uptake by land
  - More carbon release to the atmosphere

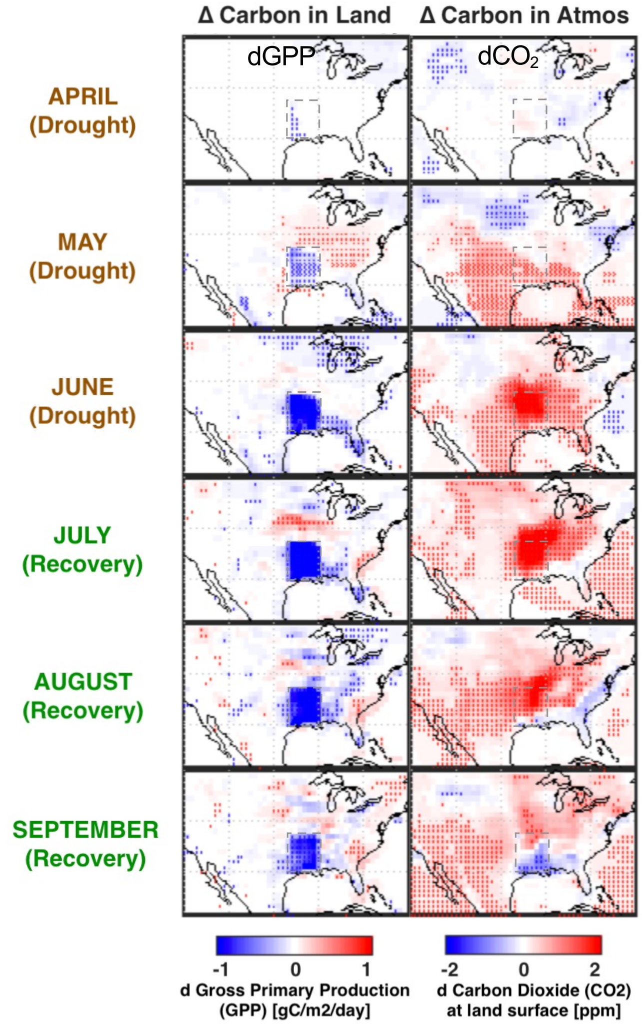
- Some effects remain even during the recovery period (Jul-Sep)



Lee et al. 2020, *JGR-bio*

Drought-induced anomaly (DROUGHT – CTRL) in land carbon and atmospheric carbon

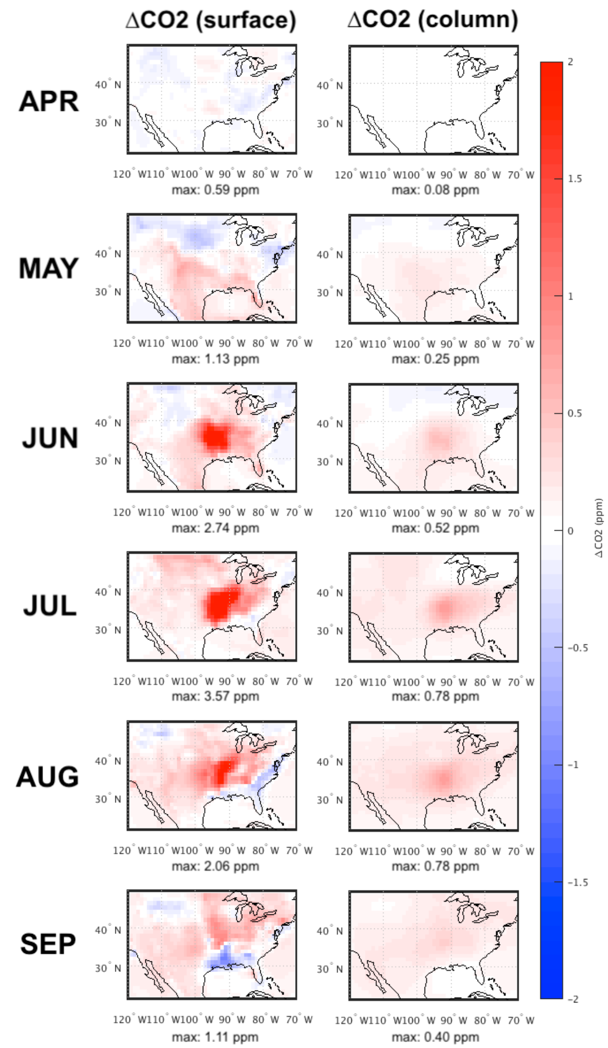
- Vegetation productivity in the drought area was reduced by 23%.
- The impact of the idealized drought on carbon is shown not only in the drought area but also in remote areas adjacent to the drought area, through induced-change in meteorology.
- Anomalous atmospheric CO_2 extended over an area three times larger than the imposed drought due to atmospheric transport.



Monthly anomalies caused by the imposed drought: (left) GPP and (right) surface CO_2 in the lowest atmospheric model layer (about 50 m). Hatched areas indicate the anomalies that are statistically significant with $p < 0.05$.

Drought-induced change in atmospheric carbon (CO_2) (surface vs. column-averaged)

- Increases in atmospheric CO_2 extend over an area larger than the imposed drought due to atmospheric transport (up to 3.57 ppm).
- However, the changes in **column-averaged** CO_2 (what is measured by the satellite), are up to 0.78 ppm. The values are near the measurement uncertainty of current greenhouse gas observing satellites.



Lee et al. 2020, *JGR-bio*

Summary
Impacts of a regional spring drought on land and atmospheric carbon

1. A regional, spring drought imposed over the lower Mississippi River Valley (~500,000 km^2) is found to reduce the land's carbon uptake up to 23% in the drought area, followed by increase in net carbon release to the atmosphere.

2. The impact of the idealized drought on carbon is shown not only in the drought area but also in remote areas adjacent to the drought area through induced-change in meteorology.

3. Better understanding the impact of droughts helps scientists better understand the processes that control carbon flux and how they manifest themselves in satellite observations (e.g., OCO-2, OCO-3, and GeoCarb).

4. Follow-up work: disentangling the interactions between meteorological and land carbon variations, which tries to quantify contributions of the atmospheric transport and the land carbon fluxes variability to the atmospheric CO_2 variability.

Impacts of biomass burning aerosols and clouds on PAR and land productivity in the Amazon

Background

- In every year, biomass burning aerosols in the Amazon alter the ratio of diffuse to direct photosynthetically active radiation (PAR) reaching the vegetation canopy and influence ecosystem productivity.

Research objectives

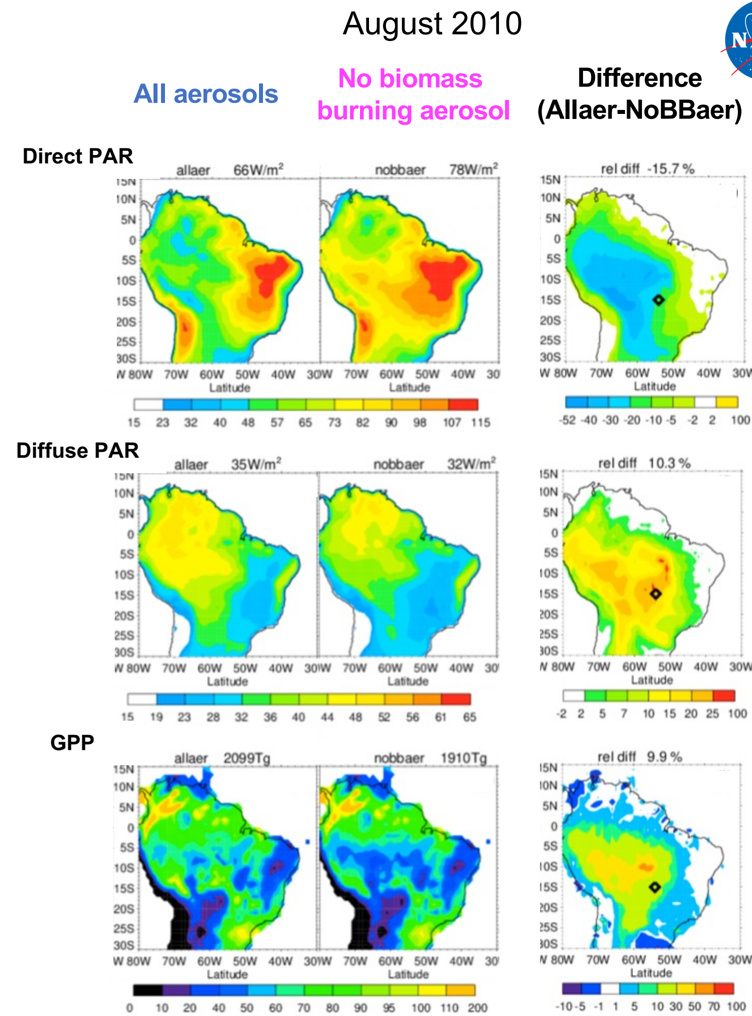
- To quantify the impact of Amazonian biomass burning aerosols on PAR distribution and ecosystem productivity.
- To investigate the joint effects of clouds and biomass burning aerosols on effectiveness of the aerosol fertilization effect within a range of the cloud interannual variability.

Experimental design

- Simulation period: 2010-2016
- [Pair 1] All aerosols (Allaer) vs. No biomass burning aerosols (NoBBaer)
  - Both simulate the same atmospheric dynamics
  - NoBBaer calculates another set of radiation fields using non-biomass aerosols only and sends different PAR fluxes to Catchment-CN
- [Pair 2] cAllaer vs. cNoBBaer
  - Same as the previous pair, except for applying a fixed biomass burning aerosol emission of year 2010.
  - Attributes the efficacy of the the role of clouds
- All simulations were run in replay mode
  - Set to MERRA-2 reanalysis at every 6 hours
  - To ensure the atmospheric conditions are close to each other.

Impact of aerosols on PAR and GPP of the Amazon ecosystem

- During burning seasons (August-October), biomass burning aerosols impacts on PAR distribution
  - 5.4% decrease in direct PAR
  - 3.8% increase in diffuse PAR
- Diffuse radiation fertilization effect
  - 2.6% increase in GPP in the Amazon (2010-2016 mean)
  - Monthly GPP enhancement can be as large as 10% (e.g., August 2010).



Bian et al. 2021, *ACP*

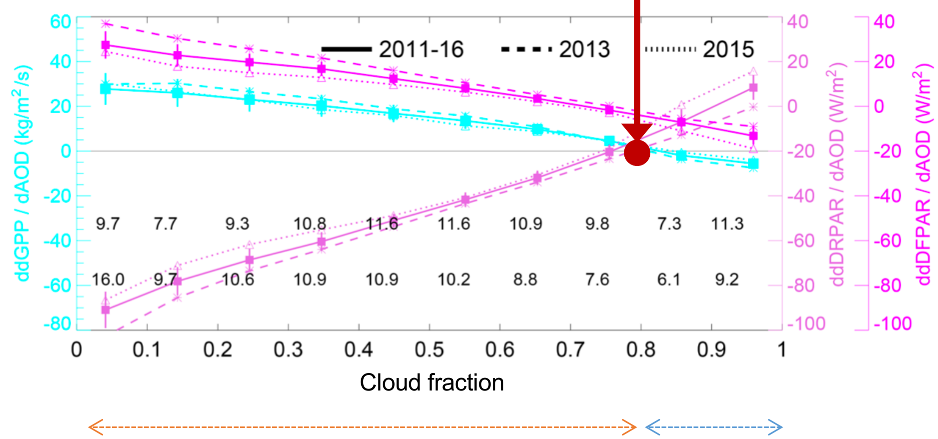
Combined effects of biomass burning aerosols and clouds

- Δ fertilization / Δ AOD was computed on gridded daily basis and then catalogued to daily cloud fraction within 10 bins.

$$\frac{dGPP_{pair1} - dGPP_{pair2}}{AOD_{pair1} - AOD_{pair2}}$$

- Efficiency of the fertilization effect
  - Highest in cloud-free conditions.
  - Linearly decreases with cloudiness until cloud fraction reaches about 0.8.

No effective fertilization by biomass burning aerosols



Biomass burning aerosols *"stimulating"* plant growth

"Inhibiting" plant growth

Bian et al. 2021, *ACP*

Summary
Effects of biomass burning aerosols and on land productivity

1. The aerosol diffuse radiation fertilization effect, which is the radiative impact of biomass burning aerosols on ecosystem productivity, increases the multi-year mean GPP in the Amazon by 2.6 % through a 3.8 % increase in diffuse PAR during the Amazon burning seasons.

2. Monthly GPP enhancement can be as large as 10 % (August 2010).

3. The efficiency of the fertilization effect is the highest in cloud-free conditions and linearly decreases with increasing cloud amount until the cloud fraction reaches about 0.8.

4. While clouds strongly regulate the efficacy of the aerosol fertilization, the large interannual variations of the biomass burning aerosols primarily control the effect on enhanced land productivity in the Amazon.

PART 2: Predictability of Land Carbon Cycle

Seasonal forecast skill of land carbon uptake

Subseasonal-to-seasonal (S2S) forecast

- In seasonal forecasts, a coupled modeling system is initialized with realistic prognostic states (for example, by data assimilation) and run forward in ensemble mode (i.e., **multiple ensemble members** are produced).
- The forecast skill stems from the system's ability to translate the initial states into future states through the proper representation of system memory and/or the evolution of coupled climate modes.
- **More than one possible projection** due to atmospheric chaos

- NASA GMAO regularly produces S2S meteorological forecasts (GEOS S2S forecast)
  - Current version (v2): Up to 9 months, being initialized about every 5 days
  - Upcoming version (v3): as large as 40 forecast simulations per month

Seasonal carbon forecast

- In recent years, the maturity of S2S forecasts has increased substantially (Doblas-Reyes et al., 2013), allowing hydrological forecasting and food security in vulnerable regions (Arsenault et al., 2020; Shukla et al., 2020). However, carbon forecasting has been addressed in only a few studies (Rousseaux and Gregg, 2017; Park et al., 2019; Séférian et al., 2018; Lovenduski et al., 2019).

- Why do we care about the seasonal carbon forecast?
  - To improve future S2S forecast system, we need the information about how the system will behave with the carbon cycle.
  - Carbon forecasts can eventually support a wider range of end users in fire management, forestry, and agriculture.

- Research objectives
  - To evaluate carbon forecast skill by utilizing S2S forecasts and a land surface model against a fully independent, remotely-sensed GPP dataset
  - To explore straightforward physical mechanisms

NASA's Catchment-CN land model

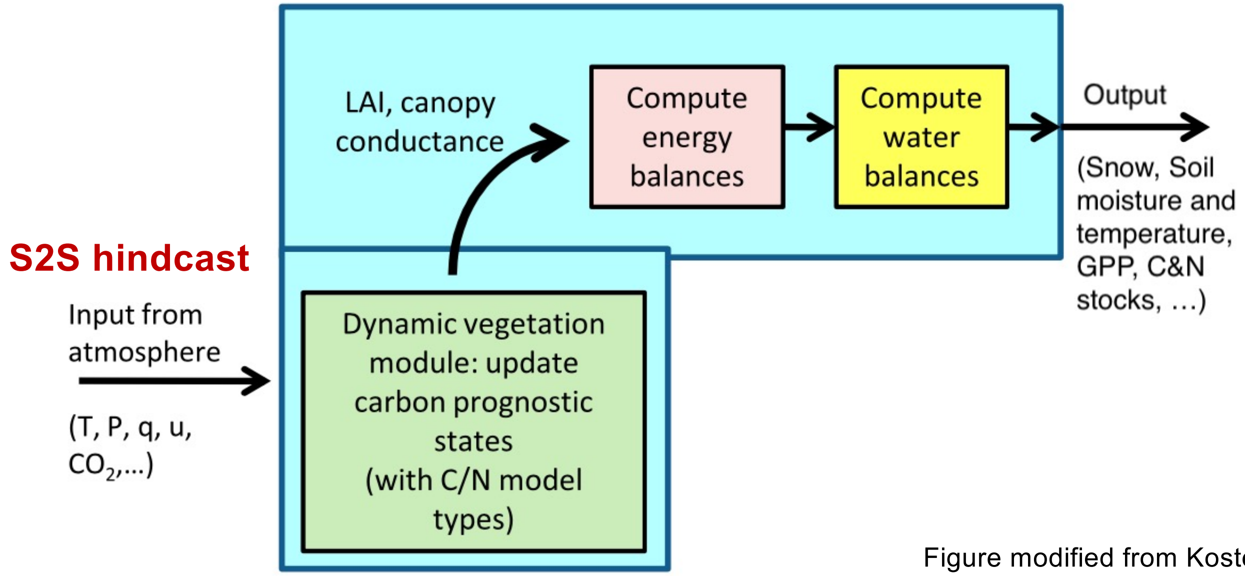
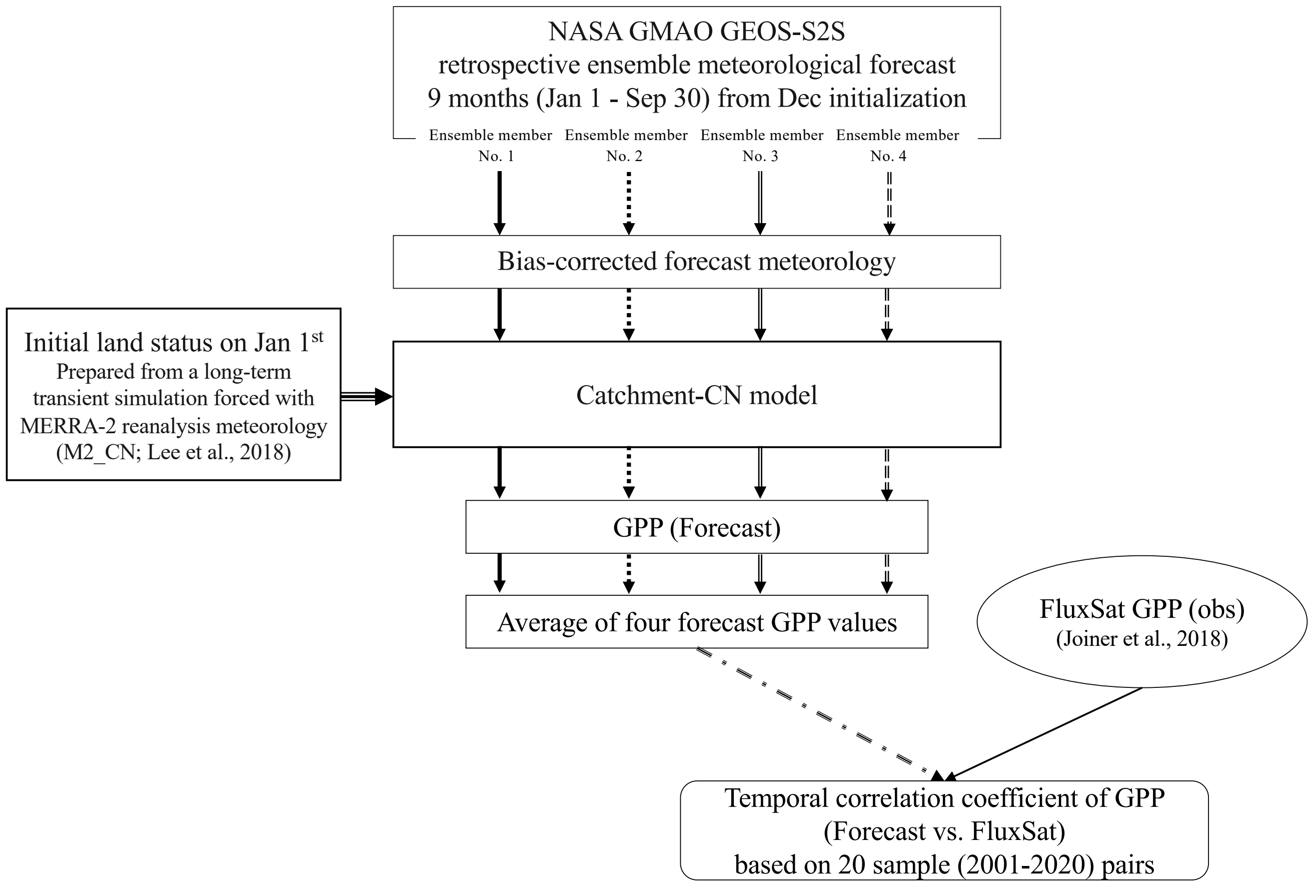


Figure modified from Koster et al. (2014)

- The stand-alone version (offline) of Catchment-CN was forced by S2S meteorological hindcasts to generate retrospective carbon forecasts.

Experimental design

- We generated **ensemble carbon forecasts** by using offline Catchment-CN model, forced with bias-corrected forecast meteorology.
- The GPP forecast skill was evaluated with the observation-based GPP (FluxSat GPP).
- Correlation coefficients (Pearson's r), based on 20 sample pairs (2001-2020).

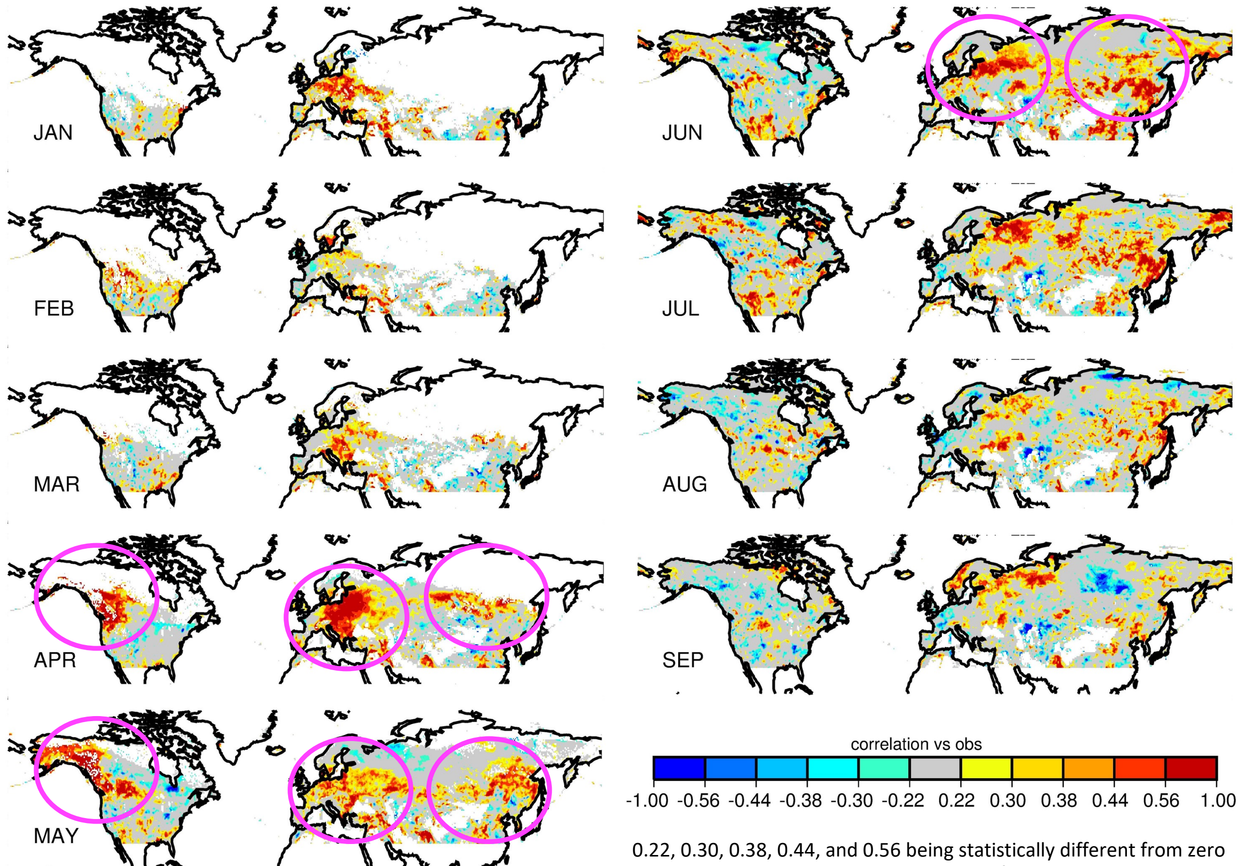


How was each carbon forecast generated?

- In each offline Catchment-CN simulation, computations were performed on **9km equal-area grid** (Brodzik et al., 2012).
- Different 9-km land elements below a 0.5° × 0.625° grid cell (that shares a same meteorological forcing) behave differently due to differences in sub-grid heterogeneity (e.g., topographical character, vegetation type, soil type).
- The average value of the atmospheric CO_2 concentration at the land surface over 2001–2020 (391 ppm) was applied globally in all simulations.
- The January 1st land initial states (snow cover, soil moisture, soil temperature, and C&N reservoir) for a given forecast year were extracted from a long-term offline Catchment-CN simulation, driven with MERRA-2 reanalysis meteorological forcing (Lee et al., 2018).

Forecast skill of monthly GPP (Forecast GPP in CTRL vs. observed GPP)

- Skillful GPP forecast in northwestern N America, eastern Europe, and Eurasia
- High skill in April and May (4th & 5th forecast lead months). However, meteorological forecast skill does not explain the high carbon forecast skill at such long lead months.
- **Some other factors (must) contribute** to the seasonal carbon forecast in mid- and high-latitudes during spring



0.22, 0.30, 0.38, 0.44, and 0.56 being statistically different from zero at the 66.7%, 80%, 90%, 95% and 99% confidence levels, respectively.

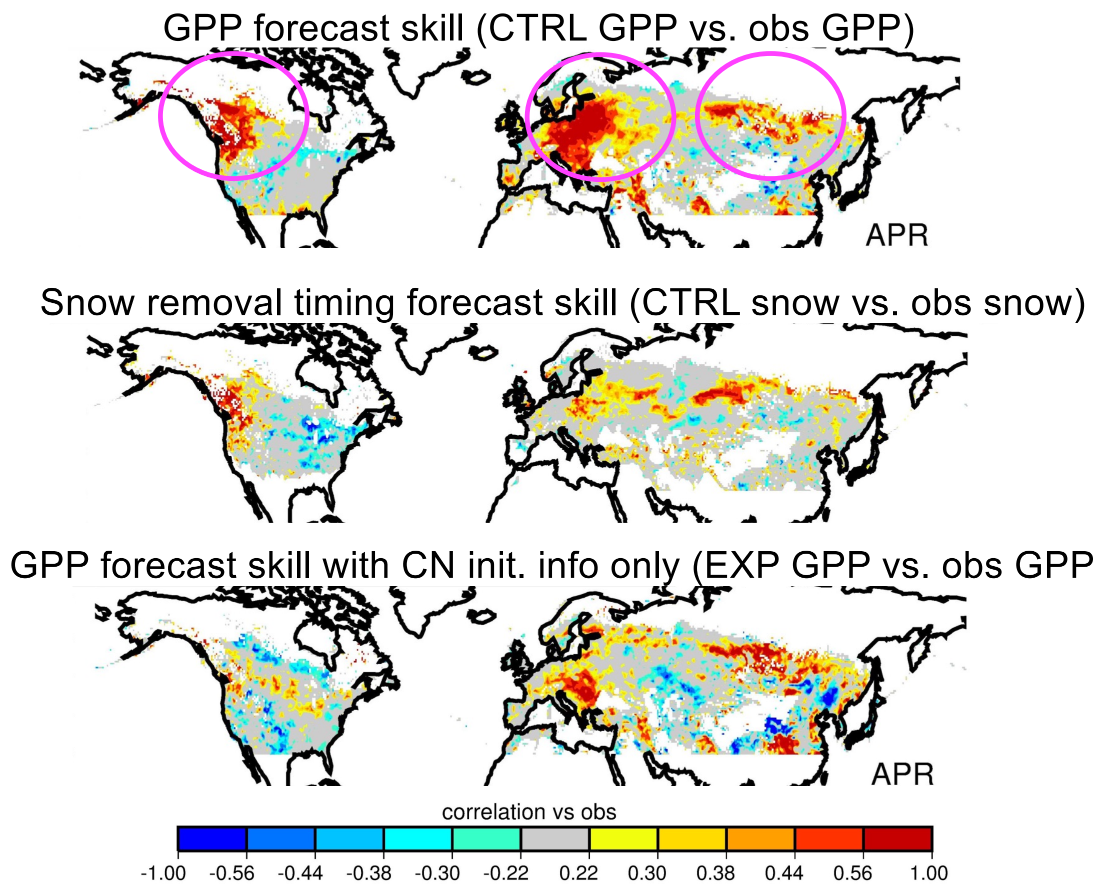
Lee et al. 2022, *GRL*

Snowcover removal timing and a supplemental experiment (EXP) design

- Snow cover removal day was defined as:
  - When daily snow mass becomes lower than 1 kg/m^2 (or 1 mm of snow water equivalent (SWE)) and,
  - The snow mass remains below the threshold for the following 7 consecutive days
- EXP suite
  - Same as CTRL, except for retaining the inter-annual variation of the CN initialization on Jan 1st and fixing other conditions as those in year 2013.
  - No inter-annual variability in forecast meteorology and snow and soil moisture initialization is allowed.

APRIL (4th lead month)
Contribution of initialization to GPP forecast skill

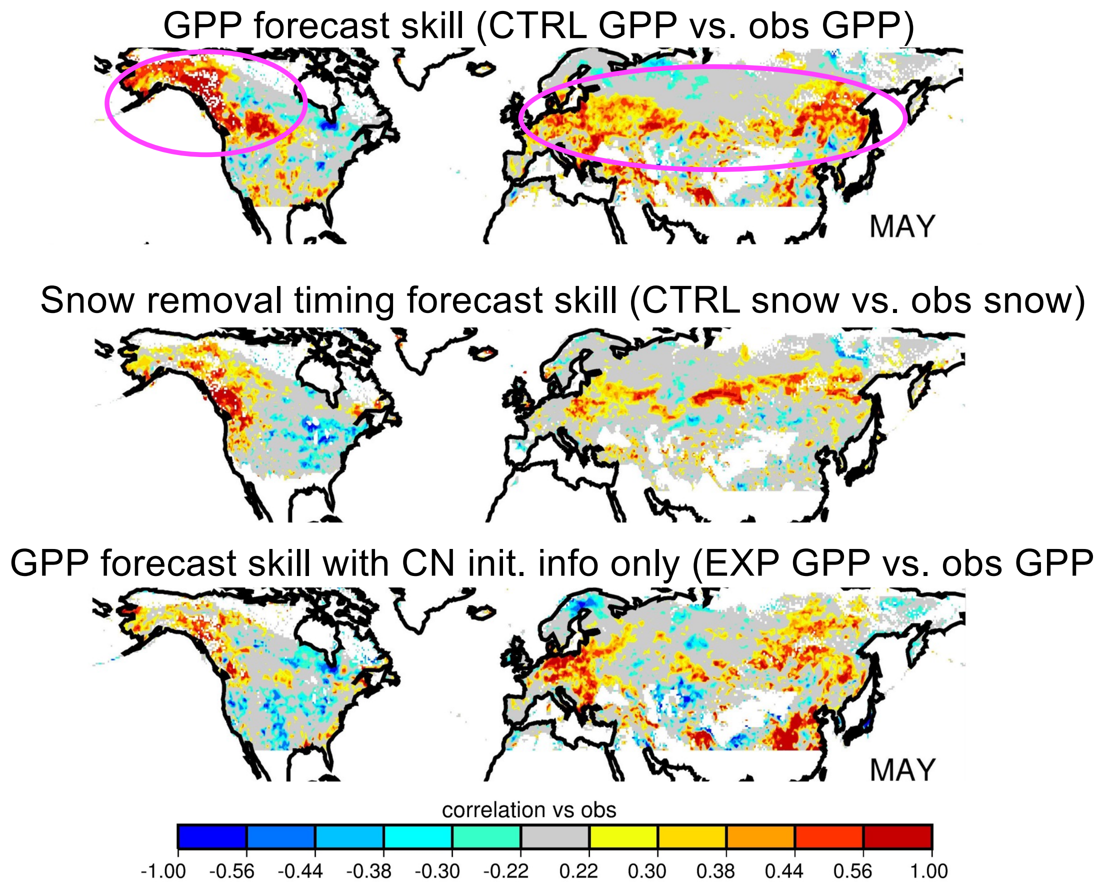
- Contribution of snow initialization appears in northwestern North America and parts of Eurasia.
- Contribution of carbon and nitrogen (CN) initialization appears in southeastern Europe and in eastern Asia.



Lee et al. 2022, *GRL*

MAY (5^{th} lead month)
Contribution of initialization to GPP forecast skill

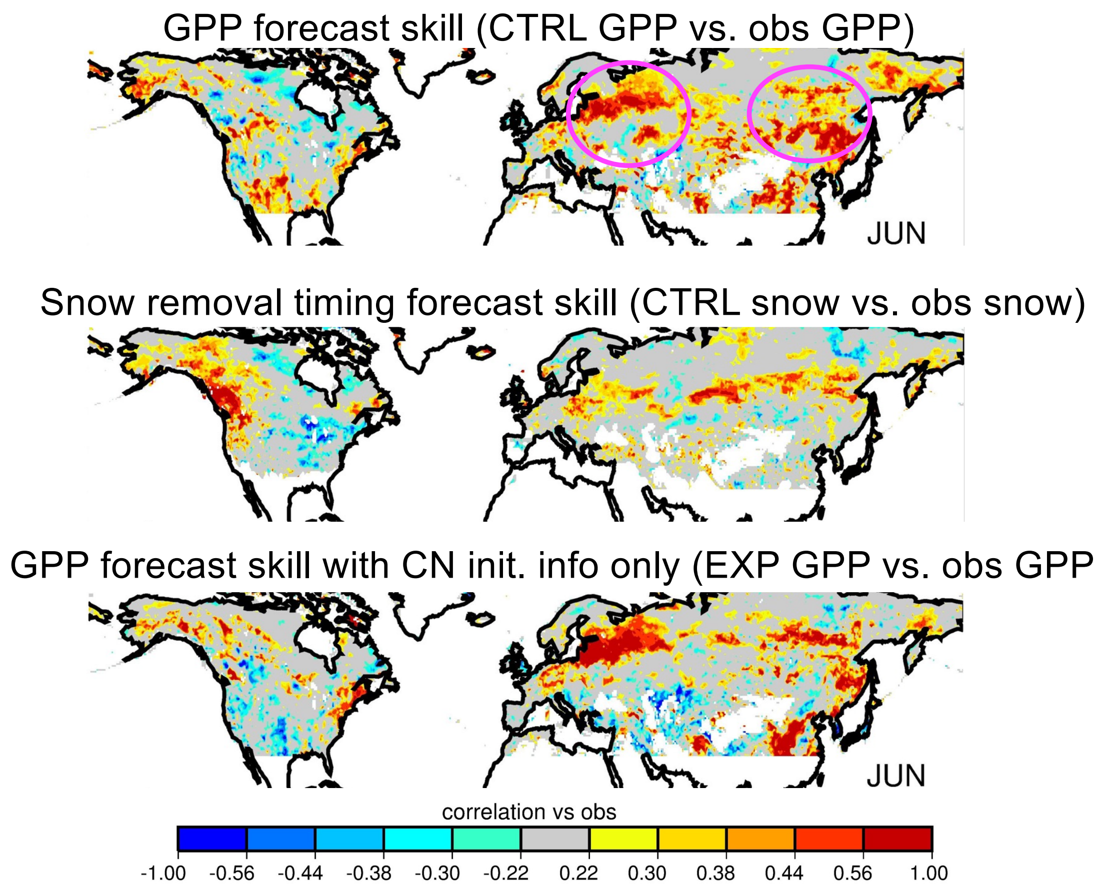
- Contribution of snow initialization still appears in northwestern North America and parts of Eurasia.
- The importance of carbon and vegetation (CN) initialization appears in part of Europe and Asia.



Lee et al. 2022, *GRL*

JUNE (6th lead month)
Contribution of initialization to GPP forecast skill

- The importance of carbon and vegetation initialization appears to be higher in later/longer forecast lead months.



Lee et al. 2022, *GRL*

Effects of snow initialization and CN initialization on seasonal carbon forecast skill

Snow initialization

- Snowpack initialized in January sit undisturbed on the surface until the spring snow-melt season.
- The information contained in the initial snowpack provides a latent predictability to the climate system (Guo et al., 2012), helping determine when the snow will finally melt away and spring vegetation growth (carbon uptake) can begin.

Carbon & Nitrogen initialization

- Another potential source of GPP forecast skill.
- The storage of carbon and nitrogen represents another relatively “slow” component of the coupled Earth system.
- Vegetation places carbon and nitrogen in different reservoirs partly for use in later production. Thus, the vegetation's established storage distribution helps set the stage for plant health and productivity during the subsequent year.

Summary
Seasonal forecast skill of land carbon uptake

1. This study demonstrate an ability to accurately forecast spring-summer carbon uptake at multi-month leads and highlights the significance of land initialization in S2S carbon forecasts.
2. The delay associated with the snow initialization is a notable lead (three to five months) for forecast skill realization. Much of the snowpack sits undisturbed on the surface until the spring snowmelt season, providing a latent predictability to the forecast system.
3. In addition to the snow initialization, the carbon reservoirs initialization is important in certain key regions and at later forecast lead months.
4. In central-eastern Eurasia, soil moisture and snow initialization may both contribute to GPP forecast skill in part by controlling growing season moisture variability.
5. Snowpack initialization and carbon reservoir initialization provide contributions to GPP forecast skill in largely complementary areas.
6. Ongoing work: evaluating the skill of carbon forecasts with the Spring initializations (i.e., initialized in March).

PART 3: Other ongoing research activities

Improved hydrometeorological prediction in an S2S system through improved treatments of evapotranspiration, runoff, and carbon cycle processes

- Funded proposal (2022-2024)
- PI: Randal D. Koster (NASA)
- Co-I: Eunjee Lee (UMBC/NASA)
- NASA Subseasonal-to-Seasonal Hydrometeorological Prediction
- To improve the forecast accuracy of hydrological variables in a full S2S forecast system
  - Calibrate the relative shapes and positions of two effective efficiency functions (ET/net radiation and runoff/precipitation) and repeat an appropriate subset of the GMAO S2S hindcasts with the full coupled model (using the enhanced LSM)
  - Include phenology-related predictability to quantify improvements in subseasonal hydrometeorological prediction

Investigation of fire carbon and its forecast skill

- Investigation of seasonal forecast skill of fire carbon
  - From the simulations used in Lee et al. 2022 paper.
  - Fire carbon forecast skill is evaluated against Global Fire Emissions Database (GFED) 4.1 fire carbon.

- Evaluation of different versions of fire modules in CLM5
  - Collaboration with Yeonjoo Kim and Hocheol Seo (Yonsei University) and NASA GMAO
  - Several fire modules (Li et al., 2014, 2016, and 2021 modules) in CLM5 are being tested.
  - Catchment-CN4.5 was found to have a significant low bias GPP due to the interplay of the intrinsic processes of fire, GPP, nitrogen, and soil water availability.

Applications of modeling tools for natural resources management

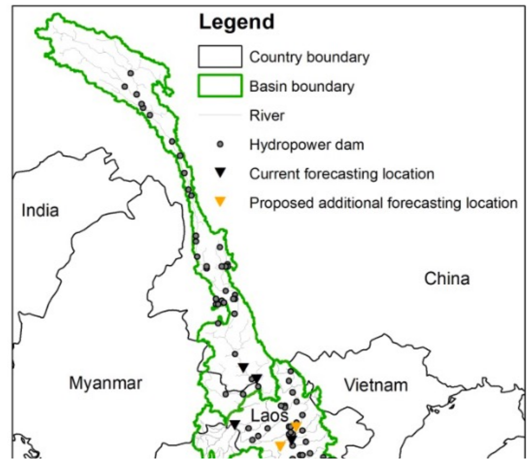
- Continued and expanded collaborative research effort
- Previously established interdisciplinary team
  - Impacts of climate change and deforestation on regional hydrology and hydropower planning in the Amazon
  - Lee et al. 2018, *Reg. Env. Chg.;* Arias et al. 2018, *Hydro. Processes;* Farinosi et al. 2019, *Earth's Future;* Arias et al. 2020, *Nature Sustainability*
- S2S Forecasting for Informed Decision-Making in the Mekong River Basin
  - Funded project for 2023-2025 (slated to start on Jan 2023)
  - NASA SERVIR Applied Science Team
  - PI: Mauricio E. Arias (Univ. of South Florida)
  - Co-Is: Eunjee Lee (UMBC/NASA), Randal D. Koster (NASA), Thanh Dang (USF)
  - To develop a decision support tool that provides sub-seasonal forecasts of water availability for the Mekong River Basin using NASA's S2S forecast system.

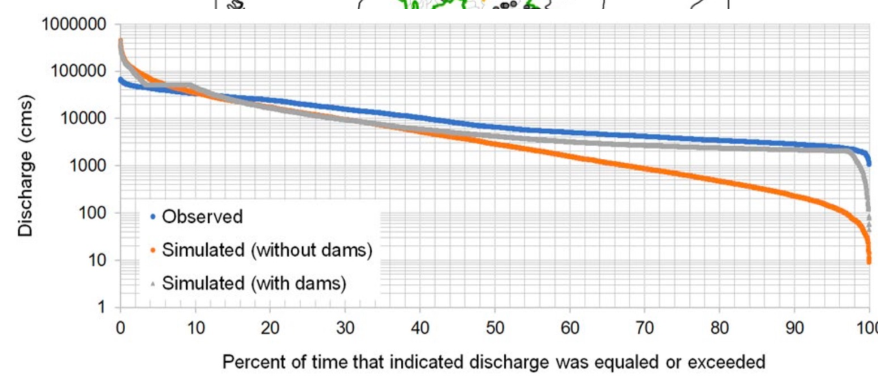
Subseasonal-to-Seasonal Forecasting for Informed Decision-Making in the Mekong River Basin

- The Mekong River Commission forecast system currently provides river level forecasts for 1~5 days along the Mekong's main stem.

- The current water availability forecast excludes hydrological alterations caused by reservoirs.

- Prediction of sub-seasonal variations in river flows on the Mekong's main stem and tributaries will be made through the joint consideration of S2S forecast runoffs and dam operations.

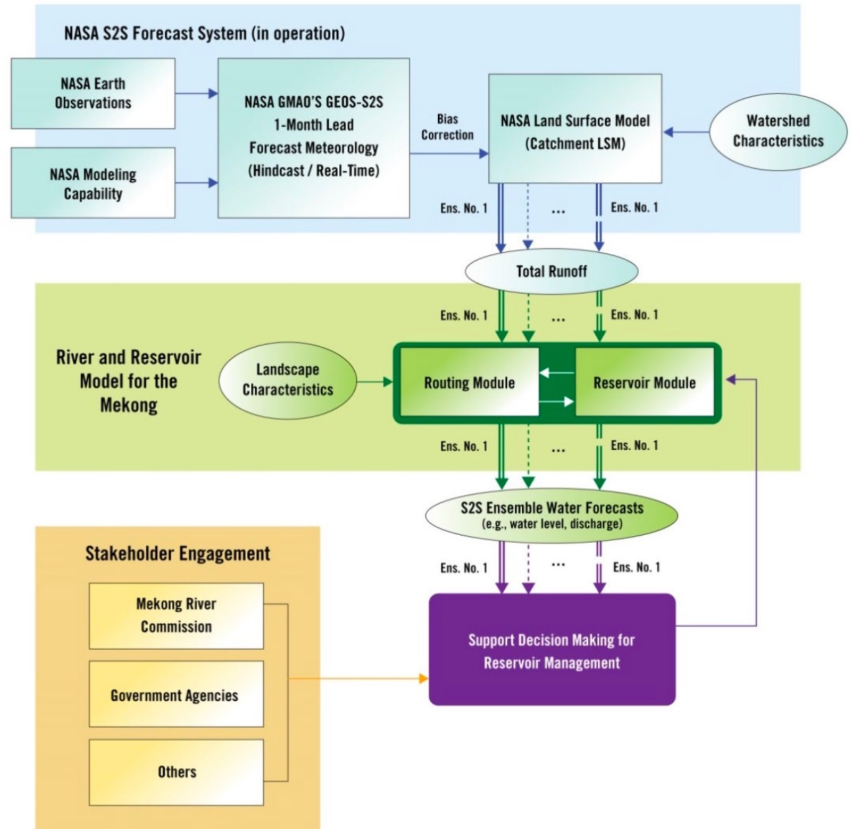




Subseasonal-to-Seasonal Forecasting for Informed Decision-Making in the Mekong River Basin

By integrating NASA's S2S forecasting platform with well-tested water models for the entire Mekong River Basin, this project aims to:

1) Increase temporal coverage from 5 to 30 days;
2) expand spatial coverage to include Mekong tributaries;
3) accounting for reservoirs and their operations;
4) improve overall sub-seasonal water forecast skill.



Summary

1. As an integral part of the climate system, the terrestrial ecosystem plays an important role in controlling the global carbon cycle.

2. Studies that include feedback processes between the land and the atmosphere show the jointly coupled effects of water-carbon dynamics and aerosol-radiation-carbon dynamics.

3. Investigation of the forecast skill of the terrestrial carbon uptake helps improve our understanding of the behaviors of the biogeochemical cycles in the forecast systems and the global carbon predictability.

4. Studies of the terrestrial carbon dynamics, as well as its interactions with other components of the Earth system, can bring more collaborative research opportunities, addressing both pure scientific and applied science questions.